

Economic feasibility analysis of low cost adsorbents for the removal of Cr(VI) from wastewater

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ABSTRACT

Population growth, coupled with industrialization and urbanization, has resulted in an increasing demand for water thus leading to water crisis and serious consequences on the environment. The effluent stream released from the industries mainly comprises of hazardous chemicals and heavy metal ions. Chromium is abundant in nature and has a dominant presence in most of the effluent streams as compared to other heavy metal ions. The present work comprises of a solution for the treatment of effluent streams containing Cr(VI). Adsorption process which is a cost effective and versatile method for the removal of Cr(VI) is selected in the present study. Low cost adsorbents such as activated tamarind seeds, activated neem leaves, sawdust, and activated flyash are developed from the naturally and abundantly available biodegradable materials to make the adsorption process economically feasible. The performance of above adsorbents is compared with the commercially available activated carbon which is a well known adsorbent used for the removal of Cr(VI) from wastewater by carrying out the batch experiments. The maximum adsorption capacity is obtained as 62.9 mg/g for activated neem leaves among various developed adsorbents, while the maximum adsorption capacity for commercially available activated carbon is found to be 71.7 mg/g. Cost analysis is carried out for the developed and commercial adsorbent shows that sawdust is the most economically viable option for Cr(VI) removal from wastewater. The social and environmental benefits obtained by industrial organization using low cost adsorbents are also discussed.

Keywords: *Cost analysis; Adsorption; Cr(VI); Adsorption capacity; Social benefit; Environmental benefit.*

1. Introduction

Water is one of the most important elements on earth. Every living being needs water for its survival. Without water everything (plants, animals, human beings, other living beings, microbes, etc.) will perish. According to the UN estimates, the total amount of water on earth is about 14,000 Billion Cubic Meters (BCM) which is enough to cover the earth with a layer of 3,000 metres depth. However the fresh water constitutes a very small proportion of this

enormous quantity. About 2.7 percent of the total water available on earth is fresh water of which about 75.2 percent lies frozen in polar regions and another 22.6 percent is present as ground water. The requirement of the fresh water in various sectors such as domestic, irrigation, industry, energy and others increases significantly all over the world. Thus water availability, both in terms of quality and quantity, has declined to such an extent owing to the rapid increase in the population and industrialization. As per the Government of India publication (Ministry of Water Resources, 2007), a basic necessity of industrial development is adequate availability of water. The increase in the utilization of fresh water for industrial purposes is a serious problem now-a-days which is faced by all through the world. The wastewater streams released from industries are contributing in contaminating the fresh water available in nature, depletion of the fresh water and increasing the water pollution.

The crisis about water resources development and management thus arises because most of the water is not available for use and secondly it is characterized by its highly uneven spatial distribution. Accordingly, the importance of water has been recognized and greater emphasis is being laid on its economic use and better management. The time has come to avert major disaster.

One of the useful solutions to such a problem is establishment of proper effluent treatment systems in industries (Babu and Gupta, 2008a; 2008b). The reclaimed wastewater, after using such treatment technique, can be reused for the same industrial processes. The effluent stream released from the industries is mainly comprised of hazardous chemicals and heavy metal ions such as chromium, nickel, copper, lead, arsenic, etc.

Heavy metals are very toxic in nature and harmful to the environment (Uysal and Irfan, 2007). The increasing contamination of urban and industrial wastewaters by toxic metal ions causes significant environmental pollution. This results in the pollution of water whereby the quality of water deteriorates, affecting aquatic ecosystems. Pollutants can also seep down and affect the groundwater deposits. These inorganic micro-pollutants are of considerable concern because they are non-biodegradable, highly toxic and have a probable carcinogenic effect (Arslan and Pehlivan, 2007). In order to combat water pollution, we must understand the problems and become part of the solution. In India and all over the world, Chromium (Cr) is dominant in most of the effluent streams as compared to other heavy metal ions. Chromium is widely used in various industries such as dyes, inks, glass, ceramics, metal finishing, corrosion inhibitors, fungicides, rubber, paints, electroplating, fertilizers, tanning, mining, metallurgical, etc. Hexavalent chromium [Cr(VI)] is one such toxic heavy metal which is considered to be a major pollutant in wastewater. Cr(VI) is highly mobile and is considered acutely toxic, carcinogenic & mutagenic to living organisms, and hence more hazardous than other heavy metals. The treatment of Cr(VI) from wastewater streams has become one of the most important ongoing environmental issues faced by all countries in today's world. There are various treatment technologies available to remove Cr(VI) from wastewater such as chemical precipitation (Uysal and Irfan, 2007), flocculation (Tels, 1987), ion exchange (Rengaraj et al., 2003), membrane separation (Kozłowski and Walkowiak, 2002), ultrafiltration (Ghosh and Bhattacharya, 2006), solvent extraction (Li et al., 2004) and electrochemical precipitation (Roundhill and Koch, 2002). These techniques are expensive and hence economically not feasible for the removal of Cr(VI) from wastewater. Adsorption technique is found to be a highly promising alternative to purify industrial effluent streams contaminated with Cr(VI) (Babu and Gupta, 2008a). Selection of an adsorbent is a key for the use of adsorption as a treatment technique for the Cr(VI) removal. There are various adsorbents such as activated carbon, activated charcoal, activated alumina etc. available

commercially for the removal of Cr(VI) from wastewater. But the cost associated with commercial adsorbents make adsorption operation very expensive. Hence, there is a need for low cost and naturally available adsorbents which can be used for the treatment of wastewater contaminated with Cr(VI).

In the present study, various low cost adsorbents such as activated tamarind seeds, activated neem leaves, sawdust and activated flyash are used to remove Cr(VI) from wastewater and their adsorption capacity is compared with the commercially available activated carbon. The cost analysis is carried out for the developed and commercial adsorbent which shows an economic feasibility of developed adsorbents for the removal of Cr(VI).

2. Materials and methods

Naturally and abundantly available materials such as tamarind seeds, neem leaves, sawdust and flyash are used to develop low cost adsorbents. Tamarind seeds, neem leaves and sawdust are available locally and flyash is collected from the power plant (NTPC, Tanda). The detailed procedure for the preparation of activated tamarind seeds (Babu and Gupta, 2008b), activated neem leaves (Babu and Gupta, 2008a), sawdust (Gupta and Babu, 2008) and flyash (Gupta, 2008) are reported in literature. The activated carbon used in the present study is purchased from market (S. D. Fine Chemicals, New Delhi).

The batch experiments are performed to obtain the adsorption capacity of different adsorbents for the removal of Cr(VI). These experiments are carried out in 100 ml borosil conical flasks. A specific amount of adsorbent is added in 25 ml of aqueous Cr(VI) solution, and then shaken for a predetermined period ranging from 17 – 67 h for different adsorbents (found out from kinetic studies) at 30⁰C in water bath shaker. The detailed procedure for batch experiments is reported in the literature (Gupta, 2008).

3. Results and discussion

This section presents the results obtained for Cr(VI) removal using newly developed (activated tamarind seeds, activated neem leaves, sawdust, and activated flyash) and commercially available adsorbents (activated carbon) by conducting the batch experiments. It also include the detailed cost analysis of different adsorbents for the removal of Cr(VI) from wastewater.

3.1. Adsorption capacity of different adsorbents

The batch equilibrium studies are useful to obtain the adsorption capacity of adsorbents for Cr(VI). An adsorption isotherm is characterized by certain constant values that express the surface properties and affinity of the adsorbent towards Cr(VI). Fig. 1 shows the adsorption isotherms for Cr(VI) removal using different adsorbents. The maximum adsorption capacity obtained is 29.7, 62.9, 21.5, 42.3 and 71.7 mg/g for activated tamarind seeds, activated neem leaves, sawdust, flyash and activated carbon respectively. These results indicate that the commercially available activated carbon shows maximum removal of Cr(VI) for any given concentration of Cr(VI) solution. The other developed adsorbents are also have significant adsorption capacity for the removal of Cr(VI) from wastewater.

Selection of any adsorbent for the removal of Cr(VI) from wastewater can not be only based on the maximum adsorption capacity. It also depends on the availability, regenerability and

economic feasibility of that adsorbent. So in the following section a detailed cost analysis is carried out to find out the cost associated with the removal of Cr(VI) from wastewater using different adsorbents.

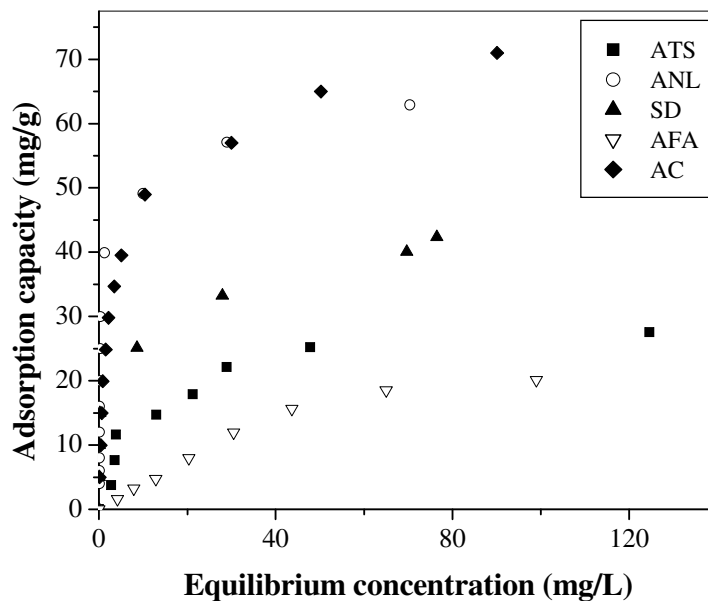


Fig. 1. Adsorption isotherms for Cr(VI) adsorption on different adsorbents at 30°C

3.2. Cost analysis

Cost analysis is the most common method used in decision making and determination of criteria to protect the environment, foreseeing possible environmental effects in application process of both physical and chemical methods. It is the most important criteria for the selection of any treatment process for the removal of heavy metals. The cost of adsorption process is mainly dependent on the cost of adsorbent used for the removal of metals from wastewater. The most common adsorbent used for the removal of Cr(VI) is activated carbon which is quite expensive. It becomes more problematic for developing countries to afford the cost and demand of activated carbon. Hence, low cost materials are sorely needed which are comparable to activated carbon in terms of adsorption capacity, economic feasibility and should be locally available. Therefore, in the present work, an attempt is made to analyze the cost of adsorbents such as activated tamarind seeds, activated neem leaves, sawdust and activated flyash. The cost for the preparation of these adsorbents is calculated based on the procedure reported in literature (Gupta, 2008). The breakup cost of each step (including physical and chemical activation procedure) and the total cost for the preparation of each adsorbent is given in Table 1. The total cost for the preparation of 1 kg of adsorbent is obtained as Rs. 36.89, Rs. 81.2, Rs. 4.4 and Rs. 35.92 for activated tamarind seeds, activated neem leaves, sawdust, and activated flyash respectively. The commercially available adsorbent (activated carbon) is purchased for Rs. 500 per kg. Based on the adsorption capacity obtained in batch study for all adsorbents, the cost of each adsorbent is calculated for the removal of 1 g of Cr(VI) from wastewater streams (Table 2).

It is found that the cost of sawdust per gram of Cr(VI) removal is Rs 0.105 which is the least when compared with the cost of other developed adsorbents. It is due to the fact that no chemical activation costs are involved in the preparation of sawdust. It is furthermore seen that it has high adsorption capacity (41.9 mg/g) for Cr(VI) removal thus making it the most economically feasible adsorbent. The costs for removal of 1 g of Cr(VI) from waste water using adsorbents such as activated tamarind seeds, activated neem leaves and activated flyash are Rs. 1.276, Rs.1.289 and Rs. 1.640 respectively. This indicates that the cost associated with these adsorbents is quite lesser when compared to that of commercial activated carbon (Rs 6.97).

Table 1. Breakup and total cost for preparing 1 kg of adsorbent from naturally available materials

S No	Material	Unit Cost (Rs.)	Activated tamarind Seeds		Activated neem leaves		Sawdust		Activated flyash	
			Amount used	Net Price (Rs.)	Amount used	Net Price (Rs.)	Amount used	Net Price (Rs.)	Amount used	Net Price (Rs.)
1	HCl	9.84	-	-	1.8 kg	17.69	-	-	-	-
2	Copper solution	348.79 per kg	-	-	0.063 kg	21.97	-	-	-	-
3	H ₂ SO ₄	4.329 per kg	1 kg	4.33	-	-	-	-	1 kg	4.33
4	NaHCO ₃	0.178 per liter	5 liter	0.89	-	-	-	-	-	-
6	Cost of Drying 1	5 per kWh	0.83 kWh (110 ^o C for 5 h)	4.16	0.83 kWh (80 ^o C for 5 h)	5.0	30 ^o C for 8 h (normal conditions)	4	0.83 kWh (110 ^o C for 5 h)	4.16
7	Cost of drying 2	5 per kWh	0.83 kWh (110 ^o C for 5 h)	4.16	0.83 kWh (110 ^o C for 5 h)	4.16	-	-	0.83 kWh (110 ^o C for 5 h)	4.16
8	Cost of heating 1	5 per kWh	4 kWh (150 ^o C for 24 h)	20	4 kWh (150 ^o C for 24 h)	20	-	-	4 kWh (150 ^o C for 24 h)	20
9	Cost of Heating 2	5 per kWh	-	-	0.83 kWh (80 ^o C for 6 h)	5	-	-	-	-
10	Net cost (Rs.)			33.54		73.82		4		32.65
11	Other overhead costs (10% of net cost)			3.354		7.382		0.4		3.265
	Total Cost (Rs.)			36.89		81.2		4.4		35.92

Table 2. Cost of adsorbent for the removal of 1 g of Cr(VI) from wastewater

S No	Adsorbent	Adsorption capacity (mg/g)	Cost of Adsorbent (Rs./kg)	Cost of adsorbent for removal of 1 g of Cr(VI) (Rs.)
1	Activated tamarind seeds	28.9	36.89	1.276
2	Activated neem leaves	62.97	81.2	1.289
3	Sawdust	41.9	4.4	0.105
4	Activated flyash	21.9	35.92	1.640
5	Activated carbon	71.7	500	6.97

The developed adsorbents are prepared from biodegradable waste materials. These waste materials require proper waste management. In the present study, waste materials are utilized for the removal of pollutants [Cr(VI)] from wastewater which helps in the waste management of these materials. The use of waste material to get a purified water for reuse is an indication of an indirect social benefit for that organization which is not measurable. When low cost adsorbent is used by industrial organizations that release Cr(VI) in wastewater, the financial benefit for the organization is Cr(VI) removal at a low cost through low costs of process and investment. Environmental benefit is Cr(VI) removal in wastewater without damaging ecosystem. Another environmental benefit is high quality of refining and use of refined water for different purposes. As a result of the environmental and financial benefits by industrial organizations, they will take measures to protect the environment and make a profit at a low social cost. Also, the organization will fulfill its social responsibility concerning the environment.

4. Conclusions

The low cost adsorbents such as activated tamarind seeds, activated neem leaves, sawdust, flyash are successfully developed. The maximum adsorption capacity of 62.9 mg/g is found for activated neem leaves which is comparable with the adsorption capacity of activated carbon (71.7 mg/g). The economic feasibility of low cost adsorbents over activated carbon is examined in the present study by making a detailed cost analysis. It is found that sawdust which is cheap and available in abundance locally is the most economical adsorbent among all the developed low cost adsorbents, and much cheaper than activated carbon. The cost of other adsorbents is also much lesser than that of activated carbon. The results of this study are useful for the industries in particular and to the planet earth in general due to the resultant social and environmental benefits.

References

- Arslan G. and Pehlivan E., (2007), "Batch removal of chromium(VI) from aqueous solution by Turkish brown coals", *Bioresource Technology*, Vol. 98, pp. 2836–2845.
- Babu B.V. and Gupta S., (2008a), "Adsorption of Cr(VI) using Activated Neem Leaves as an Adsorbent: Kinetic Studies", *Adsorption*, Vol. 14, pp. 85-92.
- Babu B.V. and Gupta S., (2008b), "Removal of Cr(VI) from Wastewater Using Activated Tamarind Seeds as an Adsorbent", *Journal of Environmental Engineering and Science*, Vol. 7, pp. 553-557.

- Ghosh G. and Bhattacharya P.K., (2006), "Hexavalent chromium ion removal through micellar enhanced ultrafiltration", *Chemical Engineering Journal*, Vol. 119, pp. 45–53.
- Gupta S., (2008), "Theoretical and Experimental Investigations for Removal of Pollutants using Adsorption", Doctoral thesis, B. I. T. S. Pilani.
- Gupta S. and Babu B.V., (2008), "Removal of Toxic Metal Cr(VI) from Industrial Wastewater Using Sawdust as Adsorbent: Equilibrium, Kinetics and Regeneration Studies", 18th International Congress of Chemical and Process Engineering (CHISA-2008), Prague, Czech Republic, August 24-28, 2008, Accepted.
- Kozłowski C.A. and Walkowiak W., (2002), "Removal of chromium(VI) from aqueous solutions by polymer inclusion membranes", *Water Research*, Vol. 36, pp. 4870–4876.
- Li C., Chen H. and Li Z., (2004), "Adsorptive removal of Cr(VI) by Fe-modified steam exploded wheat straw", *Process Biochemistry*, Vol. 39, pp. 541-545.
- Ministry of Water Resources, (2007), "Water year", Press releases, Press information Bureau, Govt. of India, January 5, 2007.
- Rengaraj S., Joo C.K., Kim Y. and Yi J., (2003), "Kinetics of removal of chromium from water and electronic process wastewater by ion exchange resins: 1200H, 1500H and IRN97H", *Journal of Hazardous Materials*, Vol. 102, pp. 257–275.
- Roundhill D.M., Koch H.F., (2002), "Methods and techniques for the selective extraction and recovery of oxo-anions", *Chemical Society Reviews*, Vol. 31, pp. 60–67.
- Tels M., (1987) "Advances in Treating Heavy Metals Containing Wastes", *Resources and Conservation*, Vol. 14, pp. 71–92.
- Uysal M. and Irfan A., (2007), "Removal of Cr(VI) from industrial wastewaters by adsorption Part I: Determination of optimum condition", *Journal of Hazardous Materials*, Vol. 149, pp. 482 – 491.